Baseline Selection in Redesign Process

Fairuz I. Romli

Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia,

43400 Serdang, Selangor, Malaysia

firomli@eng.upm.edu.my

Abstract

Product redesign process does not start from a total scratch. Instead, a reference baseline design needs to be selected as a starting point to define the required changes. So far, baseline products have been chosen usually based on the closeness of their current performance capabilities to the new driving requirements. This practice essentially presumes that such condition ensures a minimum amount of required changes, hence least redesign risk. However, it is argued that such notion can be misleading since the risk will also depend on the types and the extent of the required modifications. It is believed that the baseline product architecture plays an important role in dictating its suitability for the redesign task. A new baseline assessment procedure is proposed to address this notion. Through a sample of aircraft redesign case study, its potential to aid designers in making better judgment and selection of the proper baseline product for their redesign tasks at hand has been demonstrated.

Keywords

Redesign Process; Baseline Design; Baseline Assessment; Baseline Selection

Introduction

Over the past few decades, seller-dominated product market environment has gradually evolved into more customer-driven. It has becomes rather necessary for many manufacturers to rethink their traditional mass production to survive market competition and move towards mass customization. This shift in paradigm, among others, has increased the adoption of redesign approach in product development. In general, product redesign strategies help to make mass customization becomes more economically feasible for manufacturers (Gonzales-Zugasti et al, 2001). By reusing proven design elements or solution principles, it can enable a faster development process and adjusts costs and risks for customized product varieties (Sawhney, 1998; Muffatto and Roveda, 2000).

The backbone of the redesign process is the act of making changes to the existing design or product. It takes place against a rich background of knowledge and experience embodied in the current design, which becomes the starting point for change (Earl et al., 2005). In other words, redesign or change process requires a well-defined reference baseline and does not start from scratch. However, working with an existing or a finished product, even at conceptual level, comes with much less flexibility in comparison to a new product development that enables designers to entirely search through available design solution space. Restrictions for the redesign process correspond to the constraints due to the existing baseline product architecture that underlines the challenges in selecting suitable baseline design for the adaptation or customization tasks at hand. Furthermore, the redesign process is rarely straightforward and is also more susceptible to change propagation problems (Clarkson et al., 2001). This refers to situations where implementation of one engineering change drives other subsequent changes, which affects the budget and scheduling constraints of the redesign development (Riviere et al., 2002). As illustrated in Fig. 1, change effects are directly or indirectly transmitted through the product architecture. Propagated change effects might end up outweighing the benefits offered by the redesign process if the wrong baseline product is chosen.

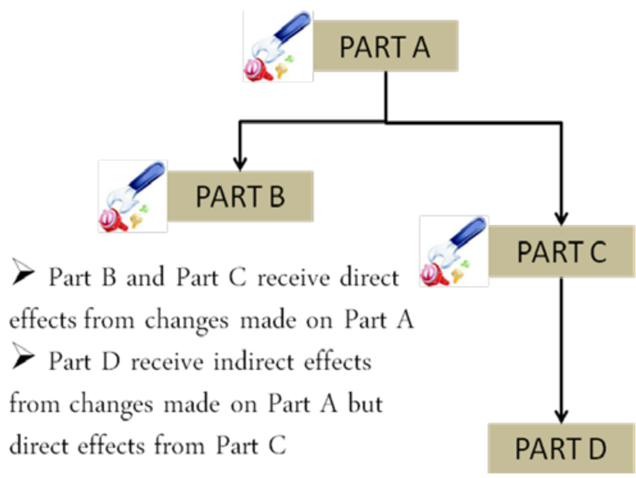

FIG. 1 PROPAGATION OF ENGINEERING CHANGE EFFECTS

So far, most baselines are believed to be selected based on their proximity to target requirements or because they are the natural choice for incremental progression within their product family. This act seems to presume that the imminence of the baseline capabilities to the driving requirements will ensure minimum amount of required changes, but this is not always true. Even if the components are closely similar, they can still have different levels of complexity and also costs for their manufacturing (*Earl et al., 2001*). Therefore, a smaller amount of product changes does not automatically mean the redesign process is easier and cheaper to be executed since that will also depends on the type and the magnitude of the required changes. With this in mind, the baseline suitability should be better reflected by its redesign cost-effectiveness and required amount of reworks. This notion leads to the development of a new baseline assessment methodology as presented in this paper. Instead of a sole focus on the closeness of the existing baseline to the requirements, the method also emphasizes on the change effects caused by the modification on the baseline design to estimate the redesign process risks. An example case study of a hypothetical aircraft system redesign is presented to highlight its potential in aiding designers to make better baseline selection for their redesign task at hand.

Baseline Assessment

The Electronic Industries Alliance's EIA649 Standard describes reference baseline as "agreed-to-description of product attributes at a point in time that provides a known configuration to which the changes are being addressed" (Smith, 2003). This supports the notion that the existing state of product architecture will influence on the way the intended changes can be implemented. Since different products have a different architecture build-ups, their required type and level of changes to satisfy similar redesign requirements are often varied. No well-known formal method or tool has been found during the literature reviews to be directly focused on evaluating the baseline suitability for redesign process from the design architecture viewpoint.

On the other hand, few available standard definitions can still be used for guidance. In general engineering design, the ability to adapt the product towards any changes in its environment, requirements and also technological advancements is called as "evolvability" (Rowe and Leaney, 1997). This is related to the inherent degree of design changeability attribute to satisfy the new arising requirements without compromising the integrity of its existing architecture (Rowe et al., 1998; Hilliard et al., 1997) and with a cost-effective process in comparison to building a new product for the similar purposes (Christian, 2004). All engineering systems can accommodate changes either statically or dynamically. This can be decomposed into four measures of system evolvability, with each corresponding to the different way the new requirements could be satisfied by the baseline design as described in Table 1 (Christian, 2004; Christian and Olds, 2005). By this notion, evolvability measure of a product system is determined by its level of difficulty to be modified in order to achieve target requirements. This can be estimated by the aggregate measure of how well it can accommodate the changes by its inherent generality, adaptability, scalability and extensibility capabilities.

TABLE I. CLASSES OF SYSTEM EVOLVABILITY

Evolvability Measure	Description
Generality	The capacity of a system to accommodate a change in requirements without altering the existing architectural design or implementation strategy
Adaptability	The capacity of a system to accommodate a change in requirements through rearranging existing system components within the current architecture and without changing other components or their integration solution
Scalability	The capacity of a system to accommodate a change in requirements by increasing the size of architectural components to hold increased loads
Extensibility	The capacity of a system to accommodate a change in requirements through adding new components or through a major change in the architecture or implementation strategy

The closest method found that considers the possible influences of baseline product design architecture on redesign process is the Methodology for Assessing the Adaptability of Products (MAAP). It is developed to assess the feasibility of adaptation for a product and includes an evaluation on its suitability to undergo the typical adaptation procedures like repair, maintenance, remanufacturing and up-/down-grading (Willems et al., 2004). Plus, three categories of product parameters are also included into the list of adaptation metrics for the assessment based on common task demands for the procedure related to product architecture composition, which are generalized as parts, connectors and spatial metrics (Willems et al., 2003). Under MAAP application, product adaptation is perceived as extension of usage for existing products beyond their initial designated operational life (Willems et al., 2003; Seliger et al., 1998). It evaluates

the product suitability to be modified for a different function compared to the one it is originally designed for. This objective is clearly different from the focus of this redesign study. However, it provides a good reference basis for the development of a new structured guideline to evaluate baseline suitability for product redesign process.

Proposed Assessment Method

While many baseline products are selected based on their proximity to the target requirements, it is argued that their architectural characteristics play a significant role in ensuring the potential success of the redesign development. Depending on baseline's existing design architecture and change requirements, the complexity of the redesign procedure can substantially vary from one baseline candidate to another. When performance requirement is modified or newly available technology is to be incorporated into it, the baseline design will have to be changed accordingly. Since each existing component often has different level of manufacturing difficulty, the complexity of the redesign process is greatly influenced by which of them are affected by the proposed changes and the impact level imposed on them. With this understanding, baseline suitability for the specific redesign case can be indicated by how well its design architecture can cope with the change requirements.

It should be realized that the most evolvable product design is not always the best option for the change implementation task at hand because it is still possible that the process will be costly or risky (Christian and Olds, 2005). Apart from the typical baseline selection based on its proximity to the requirements, redesign development risk has to be an evaluation criterion to select the appropriate baseline. All in all, the preferred redesign plan can be implied as the one with only a small number of affected parts, requiring less new parts and interrelationships, and can be accomplished with a low risk and cost (Fricke and Schulz, 2005). With this in mind, evaluation metrics in Table 1 are referred but their definition is adjusted to match the scope of a product redesign process instead of a new product development that they have been developed for. The modified definition is listed in Table 2. Furthermore, it is also favorable to have minimum affected parts and interfaces. A less complex system design will typically minimize the risk of change effects propagation since the components are not intricately linked to each other, which is addressed by MAAP through its "parts" and "connectors" metrics. To account for this, complexity criterion is added to the list of the considered product evolvability metrics as in Table 2.

TABLE 2 MODIFIED PRODUCT EVOLVABILITY METRICS

Evolvability Metric	Description
Generality	Capacity to accommodate changed or new requirements without requirement of any changes to its existing design
Scalability	Capacity to accommodate required changes only by the scaling of its existing design without requirement of any new components
Adaptability	Capacity to accommodate required changes without propagating the change effects beyond the initiating components
Extensibility	Capacity to accommodate required changes with the effects propagation allowed
Complexity	Capacity to accommodate required changes without increasing its design complexity level

For the product's generality criterion, there are two possible situations: whether the requirements can be satisfied without requiring any change to the existing product architecture or not. A zero rating is given for the former condition while the latter corresponds to a penalty rating of 100. This will be assessed for each redesign requirement and their total is taken as overall generality risk measure. Similarly, there are also two possibilities for product's scalability metric, for which the baseline product is evaluated on whether it can meet the requirements through scaling of its existing design without requirement of new components and interfaces. If this is possible, a rating of 0 is assigned to indicate a low risk level or otherwise, a penalty rating of 100 is assigned. This is done for each requirement and their total is taken as the overall scalability risk measure.

For adaptability assessment, the baseline is evaluated for its ability to contain the intended initiating changes within the directly-affected design architecture locality. In general, the efficiency of the redesign process can be estimated based on the amount of cost and efforts that it requires, which is translated into process risks when the redesigned product fails to meet all of the desired requirements. A widely-used scheme in product risk management approximates change risk as the product of its likelihood and impact rating (Clarkson et al., 2001; UK Ministry of Defense, 1996). In this case, "likelihood" is taken as a measure of possibility that the component will have to be changed during the redesign task and "impact rating" reflects on the level of effects caused by the imposed change. During early product redesign stages, if a component is considered

for modification, its change likelihood can be taken as 1. Accordingly, its probability can be assigned as 0 if it is excluded from the initial redesign plan. Meanwhile, change risk analysis is focused on the feasibility and the viability of the product design and its development (Crossland et al., 2003), which can be translated into the levels of difficulty and cost to realize the required modification. Taking these into account, adaptability risk measured by Eqn. 1 is evaluated for each change requirement. If adaptability is not possible, the highest penalty score of 100 will be assigned instead.

$$\text{Adaptability Risk} = \begin{cases} \lfloor \text{Cost}_i \times \text{Difficulty}_i \rfloor & \text{if possible} \\ 100 & \text{if not possible} \end{cases} \quad (1)$$

where Cost_i = change cost metric for initiating component i
Difficulty_i= change difficulty level metric for initiating component i

In opposite to the assessment of adaptability criterion, the change effects are allowed to propagate from the initiating components to other parts of the baseline architecture during the evaluation of the extensibility characteristic. In similar arguments as presented for adaptability, the mathematical equation to be used to estimate extensibility risk is given by Eqn. 2 and it is separately calculated for each change requirement case.

$$\text{Extensibility Risk} = \begin{cases} \lfloor \text{Cost}_i \times \text{Difficulty}_i \rfloor & \text{if possible} \\ 100 & \text{if not possible} \end{cases} \quad (2)$$

where Cost_i = change cost metric for initiating component i
Difficulty_i= change difficulty level metric for initiating component i

In regard to above equations, a proper rating scheme for cost and difficulty metrics need to be established. The System Readiness Level (SRL) index (Hobson, 2006) can be taken as an adequate reference for qualitative change risk rating since it provides a good reflection of the change process at hand by relating to the readiness of the system or the technology to be incorporated into the product's use (O'Neill et al., 2007). Based on SRL, a qualitative change risk rating scale that is reflective of the redesign process is derived as presented in Table 3. The modified SRL scale relates to the process difficulty associated with the proposed changes only. As argued, one component might have different costs to change compared to others. If two components are subject to a similar level of change impact, their incurred cost can still be significantly varied. To deal with this situation, a simple change cost rating scale is proposed in Table 4.

TABLE 3 CHANGE IMPACT RATING SCALE

Impact Level	Definition
10	The required component modification is at SRL 1
8	The required component modification is at SRL 2
6	The required component modification is at SRL 3
4	The required component modification is at SRL 4
1	The required component modification is at SRL 5

TABLE 4 CHANGE COST RATING SCALE

1	Very Low Cost
4	Low Cost
6	Medium Cost
8	High Cost
10	Very High Cost

Finally, in reference to the Design for Assembly (DFA) method in MAAP, Eqn. 3 is applied to assess relative complexity of the modified product to its baseline. The term "interrelationship" refers to connections between different product subsystems and also those within each of them. High complexity score implies that the modified product and its development are expected to be more complex than its baseline. This situation is generally not favorable since highly complex design is more susceptible to change effects propagation (*Eckert et al., 2004*).

$$\text{Complexity Score} = \left(\frac{\text{new \# of parts}}{\text{existing \# of parts}}\right) + \left(\frac{\text{new \# of interrelationships}}{\text{existing \# of interrelationships}}\right) \quad (3)$$

Once all metrics have been evaluated, overall measure to reflect on the baseline suitability for the redesign task is given by the following Eqn. 4.

$$\text{Overall Evolvability Risk, } f = \sum w_i x_i \quad (4)$$

w_i = weighting for evolvability metric i, x_i = normalized score of evolvability metric i, i = evolvability metric as tabulated in Table 2

In Eqn. 4, overall evolvability risk is calculated using normalized score of the metrics that is derived based on the worst case scenario. For generality or scalability assessment, the worst case is when each of the change requirements is assigned with a penalty score of 100, which means they cannot be accomplished without modifying the baseline design. For adaptability and extensibility metrics, the worst possible condition is for each of the initiating change components getting a risk score of 100. If more than one baseline candidate

are concurrently being considered, the normalization will use the worst case scenario among all candidates to enable a more meaningful risk comparison between them and adequately penalize candidates with higher number of initiating components. On the other hand, in Eqn. 3, ideal score of complexity metric for a single design is 2, which indicates no significant change in complexity is expected for the redesigned product in relation to its baseline. Normalization of complexity metric is in reference to the most complex architecture among the considered candidates. Thus the resultant complexity metric could be interpreted as the relative level of design intricacy between the candidates.

The candidate with the lowest overall evolvability risk measure is taken as the best baseline for the required redesign tasks. Note that the computation of redesign risks at this point only focuses on the initiating change components. This is because the complete redesign plan is yet to be determined at this point. Nonetheless, the initiating change components are believed to be sufficient to give conservative estimate on the overall redesign development risks. In general, if extensibility risk is higher than that for adaptability, change effects propagation is undesirable and the adaptability risk is likely the best that could be expected from the use of the particular baseline product for the redesign task. Hence the level of difference between adaptability and extensibility scores can be perceived as the qualitative measure of the possible reduction or increment of the redesign risks that could be effectively obtained by purposely propagating the change effects to the other components within the baseline product architecture.

Case Study: Baseline Aircraft Selection

The objective of this example study is to demonstrate the competency of the proposed baseline assessment procedure in aiding designers in making their decision regarding baseline product selection. The output from this assessment also reflects on whether the product redesign effort is well-justified against developing an original design altogether. A common rule of thumb is that, if the product redesign development requires a similar amount of costs and market lead times as an original product development for similar requirement, it is hard to justify the redesign investment. A notional aircraft redesign problem is chosen for demonstration since its high process complexity provides a good avenue to highlight the offered benefits of the baseline assessment procedure. However, note that this sample case study is simplified to ease the understanding of the proposed procedure.

The competitiveness of an aircraft from the airlines' viewpoint is often measured by its capacity and range (Condom, 2005). Based on this knowledge, formulated requirements for this sample of redesign scenario are presented in Table 5 with three considered candidates for the baseline aircraft. The driving requirements are made in reference to the estimated performance of the existing Boeing B757-200 aircraft (Boeing 757 Wikipedia), which ensures that they are reasonable in real practice. To date, the tendency is to choose a baseline based on the closeness of its existing performance capability to the target requirements. According to a simple Pugh assessment as shown in in Table 6, Lockheed L-1011 aircraft appears as a slightly better baseline candidate for this redesign task than Airbus A320 and Boeing B727-100 due to its current performance. However, it can be implied that all of them require modifications to meet the target requirements, which can potentially affect their performance. The Lockheed L-1011 aircraft most likely requires a scaling down of its existing design to improve on its gross weight. In contrast, an expected expansion of their design to accommodate more passengers and onboard fuel to extend their flight range will increase the total weight of both Airbus A320 and Boeing B727-100 aircraft, perhaps over the target. Two remaining questions after such high-level system performance assessment on baseline selection are:

- Which modification will be more difficult and risky to be executed?
- How the existing aircraft performances will be affected by the required system changes?

To provide more transparent demonstration of this baseline assessment procedure, it is assumed that the expected gross weight problems of all candidates are handled by the implementation of electro-mechanical actuators (EMA) for their primary roll control system. There may be other necessary changes depending on their existing system architecture, but this narrowed scope is adequate to demonstrate the full capacity of the procedure. It is highly possible for the proposed design changes on each of the baseline candidates to be different from each other because they correspond to different levels of performance deficiencies to the target requirements. But for simplicity, their proposed changes are taken to be similar. None of the candidate aircraft is equipped with the EMA technology and their roll control is accomplished using hydraulically-operated actuators (Wild, 1996).

TABLE 5 DRIVING CHANGE REQUIREMENTS

Parameters	Target / Constraints	Baseline Candidate		
		Airbus A320 (Airbus A320 Wikipedia)	Lockheed L-1011 (Lockheed L-1011 Wikipedia)	Boeing B727-100 (Boeing 727 Wikipedia)
Flight Range (nmi)	>= 3900	3000	4003	2700
Maximum Capacity	>= 234	180	263	149
Gross Weight (lb)	<= 255,000	169,000	466,000	169,000

TABLE 6 PUGH EVALUATION OF BASELINE CANDIDATES

Requirements	Datum	Baseline Candidate		
		Airbus A320	Lockheed L-1011	Boeing B727-100
Flight Range	>= 3900 nmi	-	+	-
Maximum Capacity	>= 234	-	+	-
Gross Weight	<= 255,000 lb	+	-	+
TOTAL		1+, 2-	2+, 1-	1+, 2-

First of all, to ease the identification of the initiating change components and predicting all possible change propagation paths, each baseline candidate is to be appropriately modelled. Since the problem scope has been narrowed down to only the primary roll control mechanism, the modelling is focused on the aileron control mechanism. Schematic diagram for primary flight roll control of Airbus A320, Lockheed L-1011 and Boeing 727 aircraft is available in (*Wild, 1996*). In short, the primary flight roll control over Airbus A320 aircraft is achieved through the deflection of available aileron surface on each of its wings. These control surfaces are actuated by electro-hydraulic servo jacks and their position is determined using the processed signals from sidestick controllers by the elevator and aileron computers. On the other hand, in the Lockheed L-1011 aircraft design, primary roll control is achieved by four aileron surfaces and their control inputs are supplied from the control wheels. The control inputs are passed through combination of mechanical cables and pushrods to the master aileron servo located at the left inboard aileron. Through mechanical links, other aileron servos will receive their respective positioning inputs from the action of the master servo. Last but not the least, the primary roll control of the Boeing B727 aircraft is achieved by the positioning of four aileron surfaces, two for each wing. The control inputs are initiated through the control wheels, which will be mechanically passed to aileron power control unit. For this study, all main components are identified and their connections are mapped into a design structure matrix (DSM). The corresponding DSM for primary roll control mechanism of Airbus A320, Lockheed L-1011 and Boeing B727 aircraft are presented in Fig. 2, Fig. 3 and Fig. 4, respectively. The symbol "x" in the figures indicates the existence of a change relationship between components of respective row and column, which means that changing the component of the column will also induce a change on the component in the row.

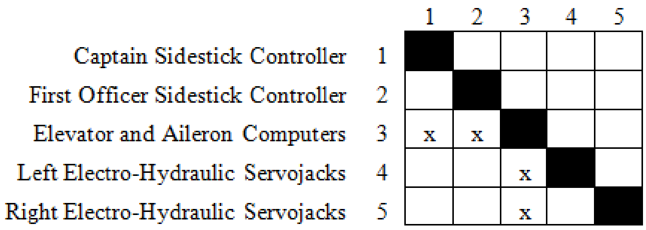

FIG. 1 DSM CHANGE MODEL FOR PRIMARY ROLL CONTROL OF AIRBUS A320

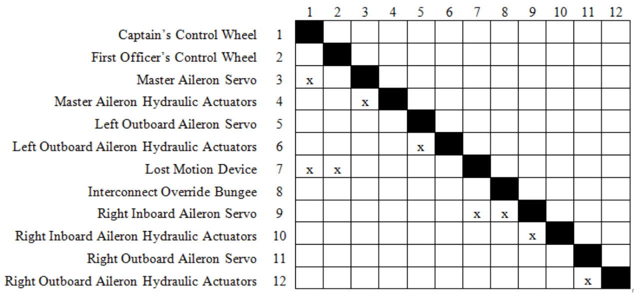

FIG. 2 DSM CHANGE MODEL FOR PRIMARY ROLL CONTROL OF LOCKHEED L-1011

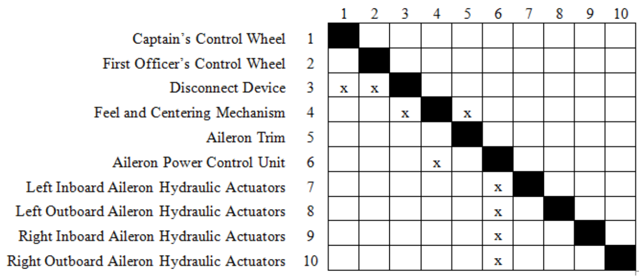

FIG. 3 DSM CHANGE MODEL FOR PRIMARY ROLL CONTROL OF BOEING B727

EMA technologies are taken to be at SRL level 4 based on available information in (Croke and Herrenschmidt, 1994; Blanding, 2007; Rosero et al., 2007; Andersson et al., 1998; Cutts, 2002; Todd et al., 1993). Expected system integration for electrical power and flight controls in AEA is illustrated in (Feiner, 1994), which is assumed to be the final resultant primary roll control system architecture for the candidates after the modification. In reference to the system described in

(Feiner, 1994) initiating change components for each of the baseline candidates can be identified and listed in Table 7. The components are the ones that are directly affected by the proposed EMA implementation, either through a replacement with new unit or installation of additional unit to match the operational requirements of the new system architecture.

TABLE 7 IDENTIFIED INITIATING CHANGE COMPONENTS

Baseline Candidates	Initiating Change Components
Airbus A320	Left Electro-Hydraulic Servojacks, Right Electro-Hydraulic Servojacks
Lockheed L-1011	Master Aileron Hydraulic Actuators, Left Outboard Aileron Hydraulic Actuators, Right Inboard Hydraulic Actuators, Right Outboard Hydraulic Actuators, Master Aileron Servo, Left Outboard Aileron Servo, Right Inboard Aileron Servo, Right Outboard Aileron Servo
Boeing B727	Left Inboard Aileron Hydraulic Actuators, Left Outboard Aileron Hydraulic Actuators, Right Inboard Hydraulic Actuators, Right Outboard Hydraulic Actuators, Aileron Power Control Unit

It can be observed that the mechanical-based control systems on Lockheed L-1011 and Boeing B727 aircraft are relatively more complex than the electrical-based control on Airbus A320 aircraft, as reflected by the list of initiating change components in Table 7. The EMA implementation has the least impact on A320 aircraft because its existing flight control is mostly electrical-based. Its only main change is to replace the electro-hydraulic servo jacks with the EMA actuators. On the contrary, the mechanical-based flight roll control on Lockheed L-1011 aircraft is the most affected by the proposed change. Apart from the hydraulic actuator, its mechanical servo units have to be replaced with those that are electrical-based. Similarly, the hydraulic actuators and mechanical-based aileron power control unit on Boeing B727 aircraft also have to be replaced. It is noted that the number of employed aileron surfaces also contributes to required redesign efforts; favoring Airbus A320 aircraft design that only has two ailerons as compared to four for both Lockheed L-1011 and Boeing B727 aircraft.

After all initiating change components have already been identified, the next step is to evaluate redesign risks associated with their modification. The generality and scalability risk assessment can be made based on the performance characteristics in Table 5, which is as tabulated in Table 8. In regards to Table 8, Lockheed L-1011 appears to be a better candidate based on the proximity of its existing performance to the target requirements in comparison to other candidates. The assessment of these two redesign risk metrics can be seen as comparable to typical baseline selection based on performance proximity to the target requirements. Even though it is known at this point that primary roll control mechanism on all candidates is not equipped with EMA implementation, it is impossible to identify which one is better suited for that redesign task based solely on the high system-level information in Table 8. Therefore, one may wonder whether Lockheed L-1011 aircraft is really the best baseline candidate due to the highest number of initiating components for the EMA implementation. Moreover, despite the fact that both Airbus A320 and Boeing B727 aircraft share similar generality and scalability risk scores, it is uncertain whether they correspond to a similar level of redesign risk. In the proposed method, the answers to these questions are captured by the measure of extensibility, adaptability and complexity metrics.

Table 9 lists the adaptability and extensibility risks for Airbus A320 primary roll control in its expected EMA implementation. Assessment of the adaptability risk is based on whether change effects due to the installation of electrical-based actuators can be contained without affecting the other components. In Airbus A320 design, this containment is possible if EMA can be operated with similar electrical power that is presently passed

TABLE 8 ASSIGNED GENERALITY AND SCALABILITY SCORES

Requirements	Airbus A320		Lockheed L-1011		Boeing B727	
	Generality	Scalability	Generality	Scalability	Generality	Scalability
Flight Range	100	0	0	0	100	0
Maximum Capacity	100	0	0	0	100	0
Takeoff Gross Weight	0	0	100	0	0	0
TOTAL	200	0	100	0	200	0
Normalized Score	2/3 = 0.67	0	1/3 = 0.33	0	2/3 = 0.67	0

TABLE 9 ADAPTABILITY AND EXTENSIBILITY RISK ASSESSMENT FOR AIRBUS A320

Proposed Redesign Changes	Initiating Change Component	Change Remarks	Adaptability Assessment		Extensibility Assessment	
			Impact	Cost	Impact	Cost
EMA Primary Roll Control Mechanism	Left Electro-Hydraulic Servojacks	Changed to EMA	6	4	4	4
	Right Electro-Hydraulic Servojacks	Changed to EMA	6	4	4	4
		TOTAL	48		32	

TABLE 10 ADAPTABILITY AND EXTENSIBILITY RISK ASSESSMENT FOR LOCKHEED L-1011

Proposed Redesign Changes	Initiating Change Component	Change Remarks	Adaptability Assessment		Extensibility Assessment	
			Impact	Cost	Impact	Cost
EMA Primary Roll Control Mechanism	Master Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Left Outboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Right Inboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Right Outboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Master Outboard Aileron Servo	Changed to electrical	10	10	1	4
	Left Outboard Aileron Servo	Changed to electrical	10	10	1	4
	Right Outboard Aileron Servo	Changed to electrical	10	10	1	4
	Right Inboard Aileron Servo	Changed to electrical	10	10	1	4
		TOTAL	800		112	

TABLE 11 ADAPTABILITY AND EXTENSIBILITY RISK ASSESSMENT FOR BOEING B727

Proposed Redesign Changes	Initiating Change Component	Change Remarks	Adaptability Assessment		Extensibility Assessment	
			Impact	Cost	Impact	Cost
EMA Primary Roll Control Mechanism	Left Inboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Left Outboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Right Inboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Right Outboard Aileron Hydraulic Actuators	Changed to EMA	10	10	4	6
	Aileron Power Control Unit	Changed to electrical	10	10	1	4
		TOTAL	500		100	

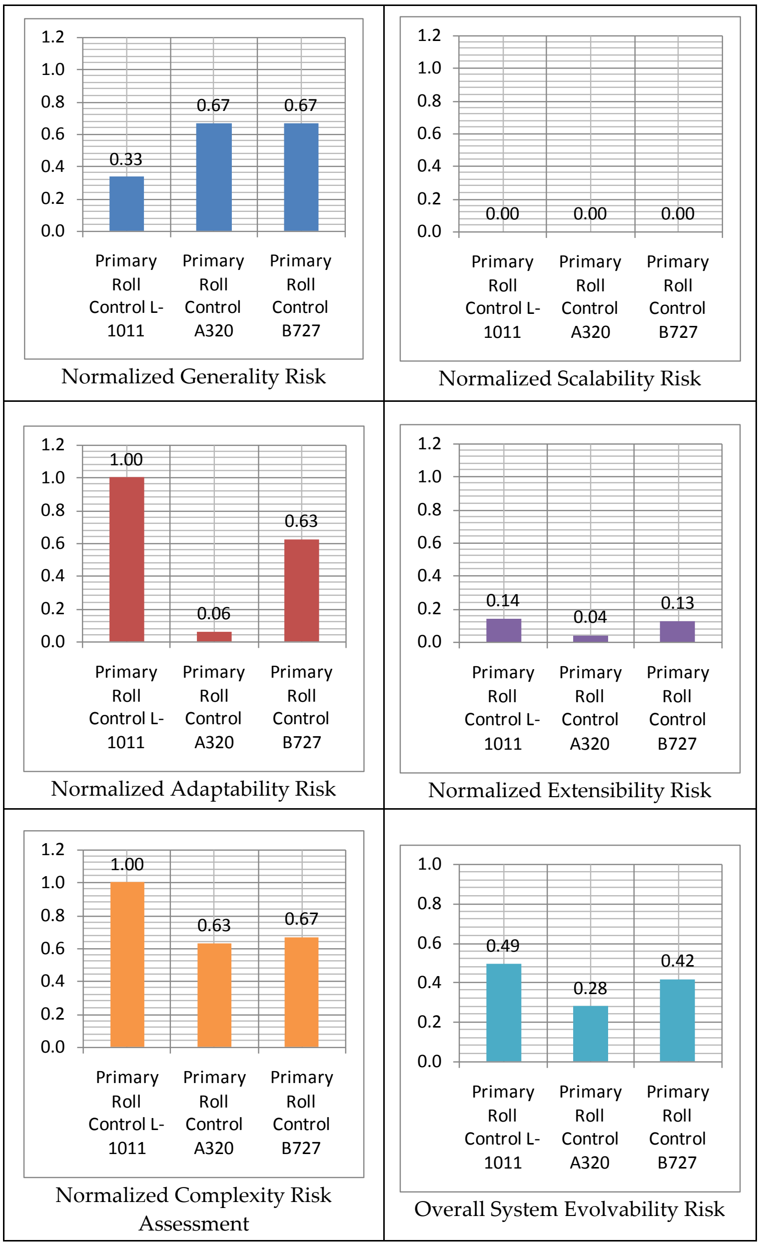

FIG. 4 COMPARISON OF SYSTEM EVOLVABILITY METRICS

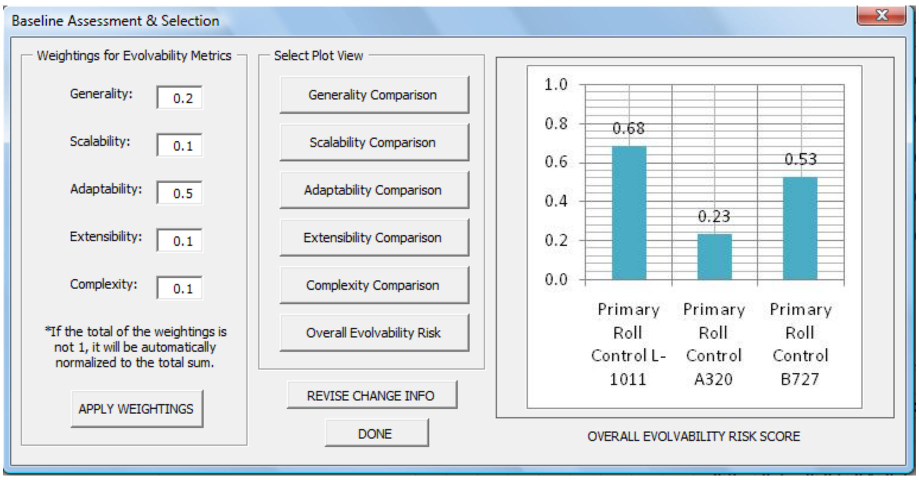

FIG. 5 BASELINE ASSESSMENT RESULTS FOR MODIFIED WEIGHTING SCENARIO

to its servo jacks. According to EMA description, its development is focused on a 270V DC power supply that is uncommon to present aircraft electrical power systems (*Karimi, 2005*), which implies that the current power supply is much lower than that expected for EMA and hence the adaptability risk here relates to the possibility that EMA can be made to perform with this existing lower power supply. Since current EMA development is taken to be at SRL 4, this additional operational constraint on its application is taken to be at a lower maturity of SRL 3. The SRL level for current development of EMA is considered for extensibility assessment since the propagation of change effects is effectively allowed in this evaluation. In addition, the measure of change cost is assigned according to the extent to which the manufacturing process will have to be changed to accommodate the implementation of the proposed design changes. The cost of Airbus A320 manufacturing process is not expected to differ much since its current design is highly electrical-based.

In similar arguments, Table 10 and Table 11 list down the adaptability and extensibility risks assessment for Lockheed L-1011 and Boeing B727 with regards to the EMA implementation, respectively. Adaptability risk scores for Lockheed L-1011 and Boeing B727 aircraft are given the maximum 100 for each initiating change component. This reflects relatively high inflexibility of the mechanical-based control onboard the two aircraft with respect to the proposed changes. For instance, in order for the existing aileron servo to contain the change effect only within its architecture locality, its modification has to include a mechanism that can convert the incoming mechanical control inputs into electrical inputs for EMAs, which is highly infeasible to be realized without affecting the electrical power subsystem and their assigned adaptability risk scores reflect this condition. Moreover, the reasoning behind their extensibility assessment is mostly similar to that explained for Airbus A320.

In terms of complexity assessment, the replacement of parts and interfaces associated with initiating change components is assumed to be made in a one-to-one condition. Each hydraulic-based actuator is replaced with an electrical-based actuator and new electrical interfaces requirements should be cancelled out by the elimination of hydraulic power lines to the actuation control unit. Hence insignificant change in the design complexity is expected for all baseline candidates. According to the constructed system models, the roll control system for Lockheed L-1011 is perceptively the most complex among the candidates. Therefore, the normalization of the complexity metric is made in reference to its total amount of parts and interfaces. In the real aircraft assessment study, the total number of parts and interfaces refers to overall aircraft system build-ups but for this example case, it is referenced only to the primary roll control system for simplicity.

Comparison of resultant system evolvability metrics for the baseline candidates is depicted in Fig. 5. If the assessment is solely based on generality and scalability risks, Lockheed L-1011 seems to be the best candidate since its existing capability satisfies two out of three formulated requirements. In comparison, both Airbus A320 and Boeing B727 aircraft satisfy only one target requirement. On the other hand, when risks regarding adaptability and extensibility redesign efforts are also evaluated, they provide an insight into the different aspect of the redesign process. Airbus A320 has the best adaptability and extensibility risk scores. This can be taken to imply that the proposed redesign changes are relatively easier to be implemented into its current system design than the other candidates. In addition, derivative design for A320 appears less complex than the others, which is favorable to minimize the risks of change effects propagation. The result in Figure 5 is derived with equal importance weighting assigned to each evaluation metric. Under this case scenario, the overall evolvability risk score can be interpreted as a combined assessment of performance and redesign process difficulty, which reflects more on the aptness of the baseline aircraft for its derivative development compared to just the closeness of its performance characteristics to the target requirements. Here, Airbus A320 aircraft emerges as the best candidate. Though its current high-level system performances are mostly in violation of the driving requirements, it can be said that it is relatively easier to make the required design changes than those for other candidates. Despite the closeness of the Lockheed L-1011 performance to the requirements, its redesign process appears much more difficult and riskier than that of the others.

To demonstrate different weighting scenario, consider the case when the manufacturer puts a high emphasis on having the smallest amount of affected components. This condition can be translated into higher weighting for adaptability risk score, which corresponds to the difficulty in containing the change effects only within initiating change components. In addition, a higher weighting for generality risk can also be considered as fewer violated requirements often indirectly suggest less conflicts to be resolved. In this case scenario, the weights for adaptability and generality risk metrics are

respectively assigned to be 0.5 and 0.2 while the other evolvability metrics are assigned with a weighting of 0.1. Assessment results for this redesign scenario are shown in Fig. 6. As expected, the difference in the overall evolvability score between Airbus A320 and other candidates becomes more pronounced in this new case scenario. This condition is primarily because its number of initiating change components is much smaller than that of other candidates, which is exactly the target behind this weighting scenario. In addition, adaptability risk related to their modification is also relatively lower than that of other candidates.

Discussion and Conclusion

It has been argued throughout this paper that redesign complexity is influenced by the characteristics of the baseline architecture. This is generally in conflict with the common approaches in baseline selection, which support design candidates with closest performance capabilities to the driving change requirements since this condition is presumed to assure minimum and less risky redesign efforts. As roughly demonstrated with the simplified Pugh Evaluation Matrix procedure, Lockheed L-1011 is probably selected as the baseline according to such notion. Nonetheless, it has also been demonstrated by results from the sample of case study that such proposition is not always true because the degree of baseline architecture flexibility also dictates the difficulty to redesign it. For instance, roll control architecture onboard the Lockheed L-1011 is relatively complicated and highly inflexible to accommodate the proposed application of EMA technology. While it is sometimes true that fewer change requirements might induce less required changes, the inflexibility of the baseline design can still make the modification very costly and risky even with minimum changes. Hence the measure of the redesign process complexity based solely on the amount of required system modifications can indeed be misleading.

As indicated by the assessment results, Airbus A320 is evaluated as the best candidate with respect to the formulated redesign tasks. Even though its existing capabilities are short from the target requirements in comparison to other candidates, its design architecture is more flexible to cope with the proposed initiating changes. A different conclusion could be derived with the same group of candidates for different redesign circumstances, which indicates the proposed baseline selection is scenario-based. For instance, instead of the EMA technology, weight savings could be achieved through installation of a better power-to-weight-ratio propulsion system. This redesign scenario may result in different best baseline candidate. In addition, the proposed changes for each of the baseline candidates to resolve their performance deficiencies with regards to the same target requirements could also be different.

To summarize, the overall evolvability risk measure in this baseline assessment procedure is essentially a compromised balance between the typical baseline selection approaches and consideration of influences of design complexity on the redesign process risk. In the sample case, the primary flight roll control system on the baseline candidates has different complexity to each other. Lockheed L-1011 has the relatively most complex control system architecture and consequently it has the highest level of redesign risk associated with the EMA implementation. In contrast, for similar EMA requirements, Airbus A320 has the lowest relative redesign risk since its control architecture is the least complex among them. This result clearly supports the proposition that the redesign process complexity is influenced by the existing system design architecture characteristics. Furthermore, it should be noted that the result is also highly dependent on the subjective assignment of the scores for this case study. A more refined method or procedure to assign these scores is needed in order to ensure the result is not overly biased to the preference of the evaluator, which should be developed in future research.

In conclusion, no well-known formal methodology or tool is found to be directly focused on the assessment of baseline suitability for redesign process, especially in the viewpoint of its current design architecture. As demonstrated by the sample in case study, sole focus on the design performances might fail to completely reflect the suitability of a baseline candidate in regards to required design reworks. Such high-level approach does not consider the existing state of the baseline architecture. In the proposed method, the baseline assessment is done through the evaluation of system evolvability metrics in Table 2. This assessment is expected to enable designers to evaluate not only the redesign suitability of a baseline candidate from the viewpoint of its current performances but also the aptness of its existing design architecture. This offers a balanced measurement of baseline suitability with respect to the actual redesign tasks at hand. Moreover, weighting scenario for evolvability metrics can be varied to match the preference of manufacturers in pursuing their own product redesign, which enables trade-off studies for different target goals of the redesign process. The presented case study is simple

and roughly formulated but the results appear to be conceptually encouraging and highlight the potential use of this proposed method. An application of this proposed method to the real product redesign cases, especially those with thousands of parts involved, is essential to further solidify this conclusion.

REFERENCES

"Defense Standard 00-56 (Part 1): Safety Management Requirements for Defense Systems", UK Ministry of Defense, Glasgow, 1996.

"DoD Directive 5000.1", Department of Defense, 2005.

Andersson, J., P. Krus, and K. Nilsson, "Optimization as a Support for Selection and Design of Aircraft Actuation Systems", 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, 1998, St. Louis, USA.

Blanding, D., "Subsystem Design and Integration for the More Electric Aircraft", 5th International Energy Conversion Engineering Conference and Exhibit (IECEC), 2007, St. Louis, USA.

Christian, J.A., "A Quantitative Approach to Assessing System Evolvability", NASA Johnson Space Center, 2004, pp. 16.

Christian, J.A. and J.R. Olds, "A Quantitative Methodology for Identifying Evolvable Space Systems", 1st Space Exploration Conference: Continuing the Voyage of Discovery, 2005, Orlando, FL.

Clarkson, P.J., C. Simons, and C. Eckert, "Predicting Change Propagation in Complex Design", ASME Design Engineering Technical Conferences and Computers & Information in Engineering Conference, 2001, Pittsburgh, USA.

Clarkson, P.J., C. Simons, and C. Eckert, "Change Prediction for Product Redesign", International Conference on Engineering Design, 2001, Glasgow, UK.

Condom, P., "Airbus Still Playing the Family Game", in Interavia Business and Technology, 2005.

Croke, S. and J. Herrenschmidt, "More Electric Initiative: Power-by-Wire Actuation Alternatives", Proceedings of the IEEE National Aerospace and Electronics Conference, 1994, Dayton, USA.

Crossland, R., J. Sims Williams, and C. McMahon, "The Practical Application of Design Risk Assessment Models", Journal of Engineering Manufacture, 2003, 217(2), 227-234.

Cutts, S.J., "A Collaborative Approach to the More Electric Aircraft", International Conference on Power Electronics, Machines and Drives, 2002, Bath, UK.

Earl, C., C. Eckert, and J. Johnson, "Complexity in Planning Design Processes", International Conference on Engineering Design, 2001, Glasgow, UK.

Earl, C., C. Eckert, and P.J. Clarkson, "Design Change and Complexity", 2nd Workshop on Complexity in Design and Engineering, 2005, Glasgow, UK.

Eckert, C., P.J. Clarkson, and W. Zanker, "Change and Customization in Complex Engineering Domains", Research in Engineering Design, 2004, 15(1), 1-21.

Feiner, L.J. "Power Electronics Transforms Aircraft Systems", Proceedings of the Wescon Conference, 1994, Anaheim, USA.

Fricke, E. and A.P. Schulz, "Design for Changeability: Principles to Enable Changes in Systems throughout Their Entire Lifecycle", Systems Engineering, 2005, 8(4), 342-359.

Gonzales-Zugasti, J.P., K.N. Otto, and J.D. Baker, "Assessing Value in Platformed Product Family Design", Research in Engineering Design, 2001, 13(1).

Hilliard, R.F., M.J. Kurland, and S.D. Litvintchouk, "MITRE's Architecture Quality Assessment", Software Engineering and Economics Conference, 1997, McLean, USA.

Hobson, B., "A Technology Maturity Measurement System for Department of National Defense: The TML System", Defense R&D Canada - Atlantic, 2006.

Karimi, K., "Electric Power System Design", Boeing MEA Seminar Series (Power Quality), 2005.Adelman, Rachel. "'Such Stuff as Dreams Are Made On': God's Footstool in the Aramaic Targumim and Midrashic Tradition." Paper presented at the annual meeting for the Society of Biblical Literature, New Orleans, Louisiana, November 21–24, 2009.

Muffatto, M. and M. Roveda, "Developing Product Platforms: Analysis of the Development Process", Technovation, 2000, 20(11), 617-630.

O'Neill, J., N. Thakur, and A. Duus, "Technical Risk Assessment: A Practitioner's Guide", A.D.o. Defense, 2007.

Riviere, A., C. DaCunha, and M. Tollenaere, "Performances in Engineering Changes Management", 4th International Conference on Integrated Design and Manufacturing in Mechanical Engineering, 2002, Clermont-Ferrand, France.

Rosero, J.A., et al., "Moving Towards A More Electric Aircraft", IEEE Aerospace and Electronic Systems Magazine, 2007, 22(3), 3-9.

Rowe, D., J. Leaney, and D. Lowe, "Defining Systems Architecture Evolvability - A Taxonomy of Change", International Conference and Workshop on Engineering of Computer Based Systems, 1998, Jerusalem, Israel.

Rowe, D. and J. Leaney, "Evaluating Evolvability of Computer-based Systems Architecture - An Ontological Approach", International Symposium and Workshop on Engineering of Computer-based Systems, 1997, Monterey, USA.

Sauser, B., et al., "From TRL to SRL: The Concept of Systems Readiness Level", Conference on Systems Engineering Research, 2006, Los Angeles, USA.

Sawhney, M.S., "Leveraged High-Variety Strategies: From Portfolio Thinking to Platform Thinking", Journal of the Academy of Marketing Science, 1998, 26(1), 54-61.

Seliger, G., W. Grudzien, and K. Muller, "The Acquiring and Handling of Devaluation", 5th CIRP International Seminar on Life Cycle Engineering, 1998, Stockholm, Sweden.

Smith, B., "Configuration Management for Transportation Management Systems", Federal Highway Administration, 2003.

Todd, J.R., J.A. Hay, and T. Dinh, "Integrating Fly-by-Light/Power-by-Wire Flight Control System on Transport Aircraft", Proceedings of the IEEE/AIAA 12th Digital Avionics Systems Conference, 1993, Fort Worth, USA.

Wild, T.W., "Transport Category Aircraft Systems", Jeppesen Sanderson Inc., Englewood, 1996.

Willems, B., et al., "Contribution to Design for Adaptation: Method to Assess the Adaptability of Products (MAAP)", Proceedings of the 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2003, Tokyo, Japan.

Willems, B., et al., "MAAP: A Method to Assess the Adaptability of Products", Proceedings of 3rd International Conference on Design and Manufacture of Sustainable Development, 2004, Loughborough, UK.